

ABSORPTION LINES IN THE GRAVITATIONAL LENS SYSTEM MG 0414+0534

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ABSTRACT

Spectra of components A1+A2 and B of the gravitational lens system MG 0414+0534 taken with the low-resolution imaging spectrograph on the Keck 10 m telescope show that the strong absorption feature seen in a low-resolution spectrum is due to a complex of Fe II lines at redshifts near that of the lensed quasar. The redshift of the lens remains unknown. © 1995 American Astronomical Society.

1. INTRODUCTION

The gravitational lens system MG 0414+0534 (Hewitt *et al.* 1992) is remarkable for its unique optical/infrared spectrum, the wavelength dependence of the flux ratios of the components, and the strength of the absorption feature observed near 8660 Å in a low-resolution spectrum. In a companion paper (Lawrence *et al.* 1995a, this volume) we report a redshift of 2.639 for the background quasar. If the absorption feature observed near 8660 Å were intrinsic to the quasar, its rest wavelength would be about 2380 Å. Although Fe II absorption features near this wavelength are often seen in quasar spectra, their equivalent width is usually much smaller than observed in MG 0414+0534. Moreover, the 2'' angular size of MG 0414+0534 means that light from the quasar passes through the lens itself. It seemed to us likely, therefore, that the absorption feature came from the lens, and that an unambiguous identification of the feature would give the lens redshift.

Accordingly, spectra of MG 0414+0534 at a resolution of 2.0 Å (FWHM) were taken with the W. M. Keck 10 m telescope on 1993 October 22 during an early engineering run of the low-resolution imaging spectrograph (LRIS; see Oke *et al.* 1995 and Cohen *et al.* 1993 for details). The slit was oriented to cover both A1+A2 and B.

Early problems with the LRIS readout electronics resulted in very high readout noise and a time-dependent bias level with strong nonrandom features that could be removed only partially. Nevertheless, a strong absorption doublet was seen near 8650 Å in both A1+A2 and B, with separation exactly as expected for Na I λλ 5889.95, 5895.92 at a redshift of 0.47. A third absorption feature near 8515 Å was unidentified, although not attributable to any obvious instrumental or night sky problem. We were sufficiently confident of the identification to submit a manuscript claiming that we had measured the redshift of the lens, but nevertheless reobserved MG 0414+0534 with LRIS after the readout problems were corrected. In this paper we report on the new observations, which have a SNR more than three times higher than the earlier ones, and which require a completely

different interpretation of the absorption seen in this interesting lens system.

2. OBSERVATIONS AND DATA REDUCTION

MG 0414+0534 was reobserved with the Keck 10 m telescope on 1994 November 7, using the low-resolution imaging spectrograph. The detector is a 2048×2048 thinned Tektronix CCD, with a peak quantum efficiency at 6500 Å of 80%. A slit 3' long illuminates an area of about 2048×800 pixels. The blue- and red-wavelength halves of the chip are read out through independent electronics.

A 1200 line mm⁻¹ grating blazed at 7500 Å was used with a 1'' slit, giving a FWHM of arc lines and unresolved night sky lines of 2.0 Å. The grating tilt put the wavelength range 8000–9200 Å on the detector. The overall throughput of the detector, spectrograph, and telescope was about 22% over this range.

The slit was rotated so that components A1+A2 (separated by 0''.41; Katz & Hewitt 1993) and B could be observed simultaneously. Two consecutive 3000 s exposures were made, followed by a dome flat and a neon discharge tube exposure, all with the telescope pointed at MG 0414+0534. The dA0 star GD 191B2B (Oke 1990) was observed with the same grating tilt for calibration.

Following bias subtraction and an adjustment for slightly different gains in the two sets of readout electronics, the flat frame was high-pass filtered, adjusted to have a mean value of unity, and used to flatten the object and arc frames.

Sky emission was subtracted using third-order polynomial fits to sky regions roughly 100 pixels wide on both sides of MG 0414+0534. Many combinations of polynomial order and region fit were tried both in order to establish the optimum method of sky subtraction, and to get an idea of the uncertainty in the absorption profile due to sky subtraction itself.

The profile of the spectrum of A1+A2 along the slit was wider than that of B, as expected from the 0''.32 projected separation of A1 and A2 along the slit. The entire profile is well fit by three Gaussians whose widths are equal to that of B, with separations as expected from the radio image. The width of B was 3.5 pixels (0''.80) in the first of the two 3000 s exposures and 5.0 pixels (1''.14) in the second. The difference in the widths between the two exposures is due in part

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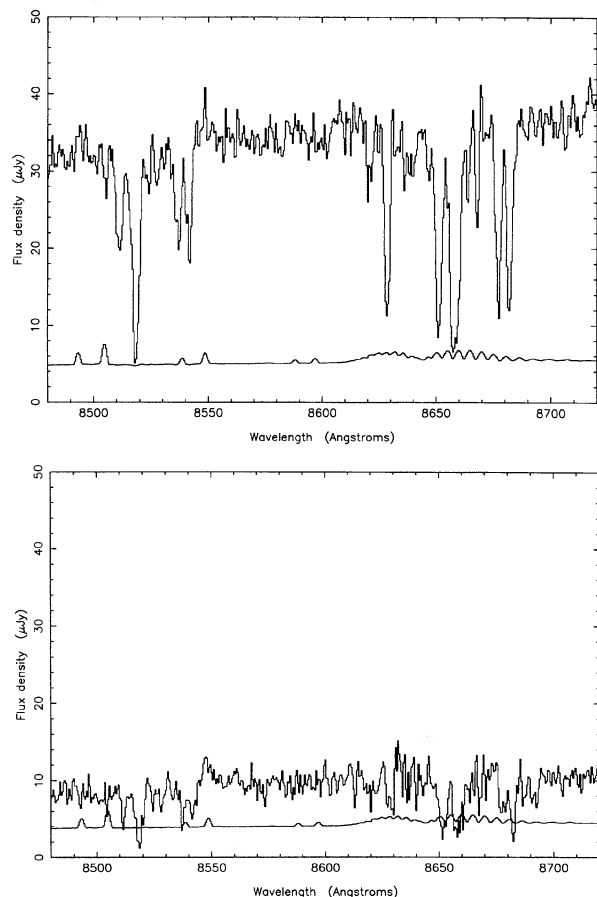


FIG. 1. Spectra of MG 0414+0534 A1+A2 (upper panel) and B (lower panel) in the region near the absorption feature. The error spectra at the bottom of each panel are based on photon noise and random readout noise only, and are dominated by night sky emission.

to the fact that the second exposure was observed at higher airmass (1.22–1.45, compared to 1.09–1.22 for the first). Even in the second exposure, however, the overlap of A1+A2 and B represents less than 5% of the total energy observed, and the spectra of A1+A2 and B were extracted separately using an optimal extraction routine.

Sixteen lines identified in the Ne spectrum were used to establish the wavelength scale. The rms error in the fitted dispersion relation was 0.03 \AA . Offsets between the wavelength scales of the arc spectrum and the MG 0414+0534 spectra due to flexure in the spectrograph were determined and removed using the positions of 40 night sky lines. The residual wavelength error on the night sky lines was 0.05 \AA .

Corrections for atmospheric extinction and instrumental response were determined from the spectrum of the standard star GD 191B2B, observed at the same grating angle. Spectra of A1+A2 and B from the two exposures were then averaged. Figure 1 shows the resulting calibrated spectra over the wavelength region where features were detected. The error spectra reflect only photon noise and the random component of readout noise.

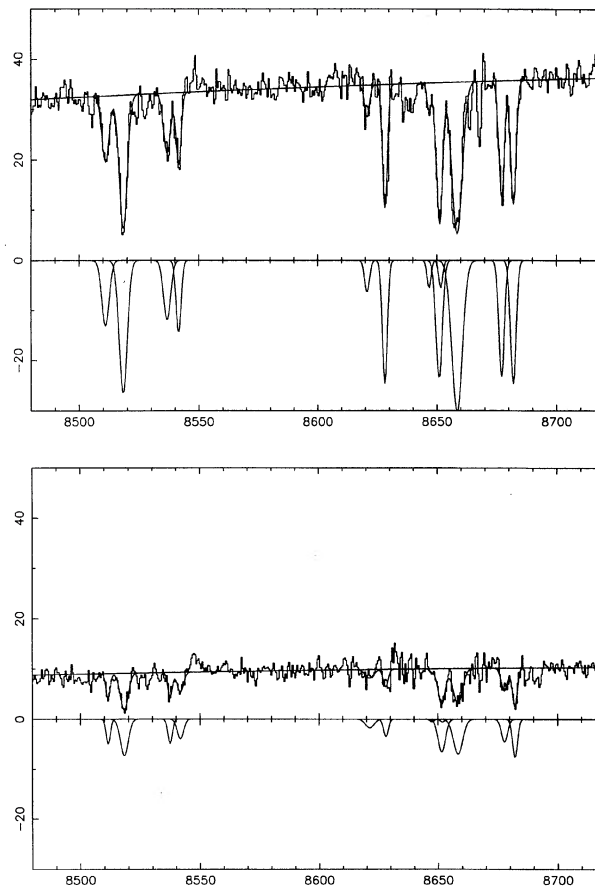


FIG. 2. Absorption features in A1+A2 (upper panel) and B (lower panel). The smooth curves are a polynomial fitted to the continuum plus Gaussians fitted to individual features.

3. DISCUSSION

The absorption feature seen in the 4-Shooter spectrum of Hewitt *et al.* (1992) is revealed in Fig. 1 to be a blend of many features. Other features are seen between 8500 and 8550 \AA . Fits to these features are shown in Fig. 2. The lines are fitted beautifully by four sets of three Fe II lines (rest wavelengths of 2343.495, 2373.737, and 2382.039 \AA). Parameters of the fits are given in Table 1. All wavelengths are heliocentric, in air. The central wavelengths of the lines in each set were constrained to be in the ratio 2343.495:2373.737:2382.039. One of the 2373.737 lines coincides with the lowest-redshift 2382.039 line, so its amplitude and width were fixed to equal those of the 2373.737 line seen near 8647 \AA . Fits were also made with the line centers free to move independently. The rms differences between the constrained and unconstrained centers is only 0.16 \AA in A1+A2 and 0.36 \AA in B. These small changes are a convincing demonstration of the line identifications, and can be taken as an estimate of the uncertainties in the line centers.

Uncertainties in the amplitudes are about $2 \mu\text{K}$, with corresponding uncertainties in the equivalent widths of 10% in A1+A2 and 20% in B. The stronger features are saturated,

TABLE 1. Absorption features of MG 0414+0534.

Name	Center (Å)	Ampl. (μ Jy)	FWHM (Å)	W_{obs} (Å)
A				
Fe II λ 2343.495	8511.32	-13.1	3.6	1.5
.....	8518.70	-26.6	4.0	3.4
.....	8537.01	-11.9	3.5	1.3
.....	8541.83	-14.5	2.5	1.2
Fe II λ 2373.737	8621.12	-6.4	2.4	0.5
.....	8628.60	-24.6	2.4	1.8
.....	8647.14	-5.5	2.0	0.3
.....	8652.03	-5.5	2.0	0.3
Fe II λ 2382.039	8651.34	-23.6	3.2	2.2
.....	8658.84	-30.2	5.2	4.7
.....	8677.45	-23.3	2.7	1.9
.....	8682.35	-24.6	2.7	2.0
B				
Fe II λ 2343.495	8511.87	-5.0	2.0	1.2
.....	8518.59	-7.3	3.8	3.3
.....	8537.74	-4.9	2.2	1.2
.....	8542.05	-4.0	3.1	1.4
Fe II λ 2373.737	8621.68	-1.7	4.2	0.8
.....	8628.49	-3.5	2.4	0.9
.....	8647.88	-0.6	2.0	0.1
.....	8652.24	-0.6	2.0	0.1
Fe II λ 2382.039	8651.89	-6.6	3.6	2.5
.....	8658.73	-7.0	4.6	3.4
.....	8678.19	-4.6	3.0	1.4
.....	8682.57	-7.7	2.4	1.9

so the ratios of amplitudes among the four systems vary considerably. Many of the lines are resolved (recall that the width of night sky lines is 2.0 Å), with corresponding velocities at half maximum up to 170 km s⁻¹.

The redshifts of the four systems are 2.63172, 2.63487, 2.64268, and 2.64474. We estimate an uncertainty of ± 0.00005 by adding the aforementioned rms differences of 0.16 and 0.36 Å in quadrature. Referenced to the lowest-redshift system these redshifts correspond to velocity differences of 0, 170, 800, and 1070 km s⁻¹. The redshift of the quasar is given by Lawrence *et al.* (this volume) as 2.639 \pm 0.002, in mild conflict (given the uncertainties) with absorption at $z=2.64268$ or 2.64474. It is clear that the Fe II absorbers lie close to the quasar, but given the difficulty of

determining an accurate redshift from a line as broad at H α in MG 0414+0534 it will be hard to say exactly how close. The fact that there are four absorbing systems so close to the quasar along a single line of sight, separated by hundreds of kilometers per second, suggests that the quasar lies in a rich environment.

The wavelength differences between the line centers of the four triplets in A and B are probably not significant.

The equivalent widths of the lines are large, particularly in the second-lowest redshift system. The observed equivalent width determined from the low-resolution 4-Shooter spectrum in Hewitt *et al.* (1992) was 20.8 Å, while the total observed W_{eq} for the lines for image A1+A2 between 8620 and 8683 Å (which give rise to the absorption feature in the 4-Shooter spectrum) in Table 1 is 13.8 Å. The differences are almost certainly the result of the low resolution of the 4-Shooter spectrum (FWHM=27 Å), coupled with the night sky features. Direct comparison of the 4-Shooter and Keck spectra shows that there is no offset in the wavelength scales, but that the shape of the absorption feature in the 4-Shooter spectrum is distorted in a pattern similar to the envelope of the night sky lines in that wavelength range.

The largest rest equivalent width for Fe II λ 2382.039 seen in a sample of 103 low- and intermediate-redshift quasars by Steidel & Sargent (1992) was 2.33 Å in Q0013-0029. The sum of the rest equivalent widths of five Fe II lines at $z \approx 1.97$ in Q0013-0029 is 6.81 Å. In MG 0414+0534 A1+A2 and B the largest rest equivalent widths seen are 1.29 and 0.94 Å, respectively. The sum of the rest equivalent widths for all twelve features is 6.08 Å in A1+A2 and 5.01 Å in B. Thus the iron absorption in MG 0414+0534 is unusual but not unprecedented.

The reader is referred to Lawrence *et al.* (1995) for more details on this interesting system, and on the significance of dusty gravitational lenses.

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